INTERTIDAL SURVEY OF HERRING SPAWN IN LOWER COOK INLET

By

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Regional Information Report[1] No. 2A93-29

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February 16, 1993

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ACKNOWLEDGEMENT

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ABSTRACT

Three intertidal surveys of herring egg deposition were conducted in Lower Cook Inlet during 1991. Two of the surveys were on Chenik Reef and one in Mallard Bay. The first survey on Chenik Reef was to estimate the biomass of spawning herring (2,781 tonnes, 3,059 tons) which deposited the eggs, while the second was to confirm a reported spawn (857 tonnes, 945 tons). The Mallard Bay survey was to relate spawning biomass estimates derived from an intertidal spawn survey (60 tonnes, 66 tons) to that obtained from aerial surveys over a 6 day period (124 tonnes, 137 tons). Estimates of eggs lost to predation and surf action were 0.39 over a 4 day interval and 0.67 over a 9 day interval in Chenik Reef and 0.52 over a 6 day period in Mallard Bay. These egg loss estimates were greater than those reported in the literature. Egg loss estimates in this study may have been confounded by overlapping spawns.

KEY WORDS: herring, spawn deposition, Lower Cook Inlet.

INTRODUCTION

The commercial harvest of sac roe herring in Lower Cook Inlet is limited to a predetermined proportion of the estimated spawning biomass. For example, the guideline harvest level in 1991 was 10% of the spawning biomass observed by the fishery managers. Aerial surveys are used to estimate the spawning biomass which probably provides a conservative exploitation rate as the observed biomass is thought to be less than the true biomass.

During the 1991 fishing season, marginal weather and water conditions permitted only one limited aerial observation of herring spawn in the Kamishak Bay District between 21 April and 1 May (Table 1). On 24 April, aerial surveyors observed 732 tonnes (805 tons) of herring near Chenik Reef. However, a 1,807 tonne (1,992 ton) harvest made on 26 April indicated the actual biomass was much greater than that observed. Subsequent aerial surveys were unsuccessful due to poor weather (Table 1).

When aerial survey conditions are poor, a spawn deposition survey may provide an alternate means of estimating spawning biomass. An intertidal herring egg deposition survey of Chenik Reef (Figure 1) was therefore conducted on May 3 to estimate the spawning biomass of herring required to account for the number of eggs observed. A second survey was made on Chenik Reef, Amakdedulia Cove, and Chenik Lagoon (Figure 2) on 16 May to confirm a herring spawn reported by a commercial spotter pilot who happened to fly over the area on 12 May. A third survey was conducted in Mallard Bay (Figure 3) on 24 May to compare the estimates of spawning biomass derived from an intertidal spawn survey with those estimated from aerial surveys. Spawning had been observed in Mallard Bay between 30 April and 22 May (Table 2).

METHODS

The intertidal surveys were patterned after the subtidal surveys conducted by SCUBA divers in Prince William Sound (Biggs and Funk 1988). Instead of diving, surveyors walked the intertidal areas of Chenik Reef and Mallard Bay at low tide. Each surveyor walked one or more randomly selected transects and systematically sampled each transect for egg deposition. Surveyors estimated the proportion of the area within a 0.1 m² quadrat that was covered by eggs as well as the number of egg layers within this area. We assumed one layer of eggs within the quadrat was equivalent to 40,000 eggs (Biggs and Funk 1988). Estimates were adjusted for observer bias, and mean quadrat egg densities were expanded by the total number of possible quadrats to obtain an estimate of total egg deposition. The spawning biomass required to produce the total egg deposition was estimated from herring sex ratios and fecundity.

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The total number of eggs, T, deposited in an area, in billions, was estimated from a two-stage sampling program similar to that described by Schwiegert *et al.* (1985). The first stage was randomly selected transects placed perpendicular to shore (Figure 1, 2, and 3). In Chenik Lagoon, however, transects were selected systematically and placed parallel to shore in an attempt to cover the most area before the incoming tide flooded the reef. The second stage was systematic quadrat sampling along the transects.

On each survey day, about four hours were available to walk the intertidal areas (i.e. two hours before and another two after low tide). The number of transects surveyed was, therefore, a function of the time required by each surveyor to walk a transect (in turn a function of quadrat interval), the number of surveyors available, the length of the shoreline, and the time available before the tide covered the area. For all sites except Chenik Lagoon, I divided the shore line into fixed length segments and used a random number generator to select, without replacement, the segments to be surveyed. All observers assembled at a common starting point and were assigned segments to survey. From the start of the study site, each observer walked the required distance to the start of their selected segments. Transects were placed along the starting boundary of each selected segment. Selected segments were always surveyed in numerical order. In Chenik Lagoon, the width of the reef was measured between the water and the high tide line. Transects were place parallel to the high tide line at 0.33 and 0.67 of the total reef width.

Quadrat intervals varied among the surveys, tending to be shorter when more surveyors were available to walk the transects. At each sample point, a 0.1 m² quadrat was selected as follows. The observer walked the prescribed interval, tossed a sampling frame anywhere within a 1 m radius of him or herself, and estimated egg densities where the frame landed. The start of each transect was the lowest high tide line marked by debris from the most recent receding tide. The end of each transect was at the water line. Observers recorded the percentage of area covered by herring eggs and the number of egg layers within each sampled quadrat. They also recorded vegetation and substrate type.

Quadrat egg counts (in thousands) within transect i were adjusted for observer bias (Appendices A-E) using the relationship between paired field estimates based on the number of egg layers observed (x) and laboratory counts of individual eggs in the same sampling quadrat (Figure 4):

$$y = e^{1.255666 + 0.775689 \ln(x)} 10^{-3} \qquad \textbf{(1)}$$

Paired data to fit the model (Table 3) was obtained as follows. The number of egg layers adhering to the marine vegetation (typically surf-grass *Phyllospadix* and red seaweed *Polysiphonia*) in three quadrats were estimated by all observers in the field from the number of

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egg layers and the percentage of coverage. Four quadrats were estimated by only one observer. All vegetation with eggs within each quadrat were then removed, placed in a labeled plastic bag, and taken back to the laboratory where the eggs were counted. Eggs that could not be removed from the substrate were counted in the field. This count was added to the laboratory counts.

The total number of eggs, T, in the study area, in billions, was estimated from the mean number of eggs per transect, in thousands, and the total number of possible transects:

$$T = N\hat{y}10^{-6}, \tag{2}$$

where N = total number of possible transects = $L/\sqrt{0.1}$, L = shoreline length (m) surveyed, $\sqrt{0.1}$ = width of transect strip or quadrat frame = 0.3162 m, $\hat{y}$ = mean number of eggs (thousands) per transect, and 10^{-6} = conversion from thousands to billions of eggs.

Mean numbers of eggs per transect, in thousands, was estimated from mean quadrat egg counts, in thousands:

$$\hat{y} = \frac{\sum_{i=1}^{n} M_i \bar{y}_i}{n}, \tag{3}$$

where n = number of transects sampled, i = transect number, M_i = total number of possible quadrats within transect i = $w_i/\sqrt{0.1}$, w_i = length (m) of transect i, and $\bar{y}_i$ = mean quadrat egg count within transect i, in thousands:

$$\bar{y}_i = \frac{\sum_{j=1}^{m_i} y_{ij}}{m_i}, \tag{4}$$

where m_i = number of quadrats sampled within transect i and y = egg density estimates adjusted for observer bias in quadrat j within transect i.

The variance estimator of T, in billions, was similar to that given by Cochran (1977) for three stage sampling with primary units of equal size. In our case, the expression was modified because primary units (transects) did not contain equal numbers of secondary units (quadrats), while the variance term for the third stage came from the observer bias regression model:

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$$Var(T) = N^2 (10^{-6})^2 \left[\frac{(1-f_1)}{n} s_1^2 + \frac{f_1(1-f_2)}{\sum\limits_{i=1}^{n} m_i} s_2^2 + \frac{f_1 f_2}{\sum\limits_{i=1}^{n} m_i} s_3^2 \right] . \tag{5}$$

The variance among transects, in thousands, was:

$$s_1^2 = \frac{\sum\limits_{i=1}^{n} (\hat{y} - M_i \overline{y}_i)^2}{n-1} , \tag{6}$$

where f_1 = proportion of possible transects sampled = n/N, f_2 = proportion of possible quadrats sampled = $\Sigma m_i / \Sigma M_i$. The variance among quadrats, in thousands, was:

$$s_2^2 = \sum\limits_{i=1}^{n} M_i^2 \sum\limits_{j=1}^{m_i} \frac{(y_{i,j} - \overline{y}_i)^2}{n(m_i - 1)} . \tag{7}$$

The variance of individual adjusted quadrat egg counts from the observer bias model, in thousands, was:

$$s_3^2 = \frac{\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} (y_{i,j} - (x_{i,j} 10^{-3}))^2}{(\sum\limits_{i=1}^{n} m_i) - 1} . \tag{8}$$

Spawning Biomass Required to Produce a Billion Eggs

The tonnes of spawning biomass required to produce one billion eggs, B', was estimated from:

$$B' = S \frac{W 10^{-6}}{F 10^{-9}} = \frac{SW}{F} 10^3 , \tag{9}$$

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where W = estimated mean weight (g) based on commercial catch samples of the male and female herring in the spawning population, S = ratio of total biomass to female biomass, 10^{-6} = factor needed to convert grams to tonnes, and 10^{-9} = factor needed to convert from eggs to billions of eggs. Estimates of S and W for Chenik were made from commercial catch samples collected on 26 April 1991 (Table 4; Yuen et al. 1992), while estimates for Mallard Bay were made from samples collected in 1990 (Yuen et al. 1991). F = number of eggs per females estimated from commercial catch samples collected in Kamishak Bay during 1990 and 1991 (Figure 5; Brannian and Yuen *in press*) where:

$$F = e^{4.790906 + 1.039448 \ln(W)} , \tag{10}$$

$r^2 = 0.82$, and $\sigma_\theta = 0.214152$. The variance of F was calculated after Parzen (1960) as:

$$Var(F) = e^{(2\ln(F) + 2\sigma_\theta^2)} - e^{(2\ln(F) + \sigma_\theta^2)} . \tag{11}$$

W and F were estimated from separate sampling programs and considered to be independent variables. Only one catch sample was taken in Kamishak Bay during 1991. Therefore it was not possible to estimate Var(S). The variance of $B'|S$ was approximated using the delta method (Seber 1982) as:

$$Var(B'|S) = S^2(10^3)^2 (\frac{1}{F})^2 Var(W) + (-\frac{W}{F^2})^2 Var(F) + Cov(WF) (\frac{1}{F}) (-\frac{W}{F^2}) \tag{12}$$

where

$$\frac{1}{F} = \frac{\partial B'}{\partial W} = -1 W^0 \frac{1}{F} , \tag{13}$$

and

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$$-\frac{W}{F^2} = \frac{\partial B'}{\partial F} = -F^{-2}W.$$ (14)

If W and F are independent variables, then their covariance would be zero and Equation 12 would simplify to

$$Var(B'|S) = S^2(10^3)^2(\frac{1}{F})^2 Var(W) + (-\frac{W}{F^2})^2 Var(F).$$ (15)

Equation 15 will underestimate the actual variance, if the covariance term is not equal to zero (i.e. if mean weight and fecundity were not independent). $Var(B'|S)$ may also underestimate $Var(B')$ since S is assumed to be known when in actuality it is a random variable ($Var(S)$ is not available).

Egg Loss

The estimated proportion of eggs removed from the study area by predation or wave action, R, between the time of spawning on 24 April and the survey on 3 May was:

$$R = 1 - \frac{\hat{y}_{3May}}{\hat{y}_{24April}}.$$ (16)

The total estimate of R was converted to an instantaneous rate using the general relationship (Ricker 1975):

$$Z = \frac{-\ln(1-R)}{9},$$ (17)

where 9 = number of days between 24 April and 3 May. From this, R could be estimate between any pair of dates t_1 and t_2 using:

$$R = 1 - e^{-Z(t_2 - t_1)} .$$

(18)

Biomass

Estimated spawning biomass (tonnes) in the survey area, B, was calculated from the tonnes of spawning herring required to produce the eggs observed, adjusted for egg removal due to predation and storm generated wave action:

$$B = \frac{TB'}{1 - R} ,$$

(19)

The estimates of T and B' were derived from separate sampling programs and were considered to be independent. The exact variance for the product of the independent random variables T and B', conditioned on R, was given by Goodman (1960) as:

$$Var(B|R) = \frac{T^2 Var(B') + B'^2 Var(T) - Var(T) Var(B')}{(1-R)^2} .$$

(20)

However, Var($B'|S$) was substituted for Var(B') because Var(S) is not available.

RESULTS

Although both the east and south sides of Chenik reef were surveyed, eggs were found only on the south side (Figure 1). The surveyed shoreline length on the south side was 1,500 m, average transect length was 375 m, mean egg density was 798 eggs/m^2, and four surveyors walked the transects (Figure 6 and Table 5).

I asked Wes Bucher, the ADF&G area management biologist who walked Chenik reef on 24 April, to examine the egg calibration samples that we collected from the same reef 9 days later. He felt egg densities on 24 April were 3 times greater than the samples collected on 3 May. That ratio was used to set R at 0.67 over the 9 day interval between 24 April and 3 May. An estimated 195 tonnes (214 tons) of herring would have been needed to produce the 4.53 billion eggs estimated in the survey. However, only 7% of the herring in the 26 April catch sample had spawned (i.e. were spent). If the 195 tonnes (214 tons) represented only 7% of the total biomass present, then 2,781 tonnes (2,523 tons) of herring may have been present on 24 April

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(Table 6). This estimate would be in agreement with the observed commercial harvest of 1,807 tonnes (1,992 tons).

The Chenik Reef survey on 16 May survey revealed that eggs were still present on the south side and that new eggs had been deposited on the east side. This survey covered a larger area than the previous survey and eggs were also found in Amakdedulia Cove and Chenik Lagoon (Figure 2).

Mean egg density on the southern reef had decreased from 798 to 721 eggs/m^2 (Table 5 and Figure 7). We estimated R to be 0.096 over the 22 day interval (Equation 16) which was considerably less than our earlier estimate of 0.67. The difference could have been due to another spawn occurring between surveys which masked some of the egg loss. However, it was more likely that eggs from the first reported spawn hatched after a 14-21 day incubation period, and eggs seen during the second survey were from another spawn reported on 12 May. R was therefore estimated (Equation 18) to be 0.39 over the 4 day interval between 12 and 16 May (Tables 7). About 181 tonnes (200 tons) of herring would have been required to deposit the 7.8 billion eggs estimated to be present on this reef (Table 7). In the second survey, mean transect length increased to 490 m because tides were lower (Table 5).

The surveyed shoreline length on the eastern reef was 1,000 m, average transect length was 225 m, and mean egg density was 5,417 eggs/m^2 (Figure 8 and Table 5). Eggs were not seen on this reef during the first survey, so I was confident that these eggs were from a more recent spawn. The estimated spawning biomass required to deposit 12.19 billion eggs on the eastern reef was 283 tonnes (312 tons; Table 8).

Egg density in Amakdedulia Cove appeared to be uniform within a 202 m strip running parallel to the shoreline, between 255 and 457 m from the high tide line. The surveyed shoreline length on the eastern reef was 1,880 m, length of the single transect was 607 m, and mean egg density was 267 eggs/m^2 (Table 5). A 71 tonne (78 ton) spawning biomass would be required to deposit 3.05 billion eggs in Amakdedulia Cove (Table 9).

Eggs in Chenik Lagoon were concentrated on the outer edge of the reef. The surveyed shoreline length was 1,676 m, average transect length was 373 m, and mean egg density was 2,809 eggs/m^2 (Figure 9 and Table 5). An estimated 410 tonnes (452 tons) of spawning biomass would have been required to deposit 12.19 billion eggs in Chenik Lagoon (Table 10).

In Mallard Bay, surveyed shoreline length was 500 m, average transect length was 713 m, and mean egg density was 578 eggs/m^2 (Figure 10 and Table 5). Mean number of days between observed spawn (12-24 May) and the egg deposition survey was six. Egg loss over the 6 day interval between 18 and 24 May was estimated to be 0.52 (Equation 18; Table 11). An estimated 60 tonnes (66 tons) of spawning biomass would have been required to deposit 2.06 billion eggs in Mallard Bay (Table 11).

DISCUSSION

Estimated intertidal egg loss in this study, 0.67 over a 9 day period (Table 12), was considerably greater than the 0.25-0.40 estimate proposed for Southeast Alaska by Montgomery (1958). Egg loss estimates of 0.1 used in Prince William Sound studies may not apply here as they were obtained from studies of subtidal spawning (Haegele et al. 1981).

My egg loss estimates may still be low due to the effects of multiple spawns occurring in the same area over time. James Brady, ADF&G regional management biologist, also walked Chenik reef on 24 April but he estimated egg coverage, where eggs were present, to be 0.125 of the surface area. That estimate was less than my mean estimate of 0.144 on 3 May, excluding quadrats where eggs were absent. I think another spawn occurred between 24 April and 3 May, since the low 7% spawnout rate in the 26 April catch sample suggested spawning was not completed by that date. Furthermore, egg densities from the second survey on 16 May were greater than expected, presumably the result of a spawn that occurred on 12 May.

Data from the second survey of south Chenik reef were difficult to interpret. If water temperatures in Kamishak Bay were 7.7°C herring eggs could have hatched in 19 days (Wespestad and Moksness 1990). In that case, the eggs present during the second survey may have been from a spawn which occurred after 24 April.

The estimated 60 tonnes (66 tons) of spawning biomass required to deposit 2.06 billion eggs in Mallard Bay was about half of the 137 tonnes (151 tons) observed by aerial surveyors (Table 2). However, it was not clear whether herring observed each day were the same as those observed the previous day or new herring which moved into the area.

If Lower Cook Inlet intertidal surveys are conducted in the future, egg loss should be estimated by monitoring egg densities in several plots over time. Dates of subsequent spawning episodes and water temperatures should also be recorded. Eggs from the entire 2-3 week incubation period should also be preserved, measured (diameter), and examined for presence of eyed eggs, etc. to allow more accurate estimates of spawn dates. During the present study, two separate spawns in Mallard Bay were easily discerned from differences in egg diameter and the presence or absence of eyed eggs. However, dates of spawning could not be estimated.

Spawning biomass estimates based on egg deposition represented only a small fraction of the total spawning population observed during aerial surveys. Not only were additional herring spawns observed outside of the egg survey areas, but intertidal egg surveys were not able to account for multiple spawns or subtidal spawning. I do not recommend increasing the number of beaches surveyed at the expense of transects surveyed. If intertidal surveys are conducted in the future, at least four observers should be used to survey a greater number of transects to improve variance estimates (Table 13). To accomplish this, only one beach or reef would be surveyed per day to allow more time for gathering data instead of traveling among study sites. I also recommend randomly selecting both quadrats and transects to simplify the calculation of among quadrat variance (Equation 7).

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Table 1. Herring spawning biomass estimates (tons) based on aerial surveys, Kamishak Bay District, Lower Cook Inlet, 1991.

Date	Survey Conditions	Dry Bay	Oil Bay	Iniskin Bay	Cottonwood Bay	Ursus Cove	Fort. Bluff	Bruin Amakd.	Chenik Nordyke	Kamishak	Douglas Reef	Augustine Island	Total
4 21	fair			0		0	0	0	0	0	0		0
4 23	good	0	0	0	0	0	0	0	0	0	0	0	0
4 24	fair			0	0	0	0	0	568	237	0		805
4 26	fair			0	0	0	0	0	0	0	0		0
4 27	poor												
4 28	poor												
5 1	poor												
5 3	poor												
5 6	poor												
5 7	poor												
5 8	poor												
5 15	good	0	0	517	0	56	12	406	6	0	0		997
5 16	fair	0	0	359	0	81	17	27	0	0	0		484
5 19	fair	0	0	107	0	0	0	8	0	0	0		115
5 22	good	0	119	502	3	335	67	110	0	0	0		1136
5 24	excellent	0	0	0	0	0	0	0	0	0	0		0
5 31	good	3	0	0	0	123	0	0	0	0	0		126
6 12	fair	2	0	0	0	0	0	0	0				2
Total		5	119	1485	3	595	96	551	574	237	0	0	3665

[a] If more than one survey was flown per day, either the larger estimate or the results from the survey with the best survey rating was used.

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Table 2. Herring spawning biomass estimates based on aerial surveys, Southern District, Lower Cook Inlet, 1991.

date	Survey Conditions	Bluff Point	East Spit	Mud Bay	Bear Cove	Mallard Bay	Glacier Spit	Peterson China Poot	Tutka	Total
4 30	good		0	195	0	0	0	0		195
5 1	good			84	6	0	0	0	0	90
5 3	good			13	0	0	0	0		13
5 6	good			0	0	0	0	0		0
5 12	good		0	186	0	43	0	0		229
5 15	fair		0	0	0	0	0	0		0
5 17	good		0	0	0	23	0	0		23
5 20	good		0	15	0	9	8	0	0	32
5 22	excellent	0	0	0	0	47	2			49
5 24	excellent		8	0	58	15	0	0	223	304
Total		0	8	493	64	137	10	0	223	935

Table 3. Observer estimates of egg density in the field, laboratory egg counts, and observer counts adjusted for bias collected on 3 May.

% Cover x Number of Egg Layers	Number of Eggs		
	Observer Counts	Laboratory Counts	Observer Counts Corrected for Bias
0.0025	100	117	125
0.0100	400	117	366
0.0100	400	117	366
0.0100	400	1,294	366
0.0500	2,000	2,366	1,276
0.0500	2,000	1,740	1,276
0.0700	2,800	1,740	1,657
0.1000	4,000	1,740	2,185
0.1000	4,000	5,252	2,185
0.2000	8,000	5,252	3,740
0.2000	8,000	5,252	3,740
0.2500	10,000	5,252	4,447
0.5000	20,000	2,280	7,614
3.0000	120,000	25,528	30,563

Table 4.   Age, sex, and size composition of herring sac roe harvest, Chenik, 26 April 1991.

	Age	Sex (No.)					Total No.	Percent of Total	Weight			Length			Biomass		
		Male	Imm. Female	Ripe Female	Spawned Female	Unknown			Mean (g)	SD	Number Weighed	Mean (mm)	SD	Number Measured	No. Fish X 1000	Tons	Tonnes
	1																
	2																
	3	66	6	27	1	0	100	9.9	77	10.7	100	181	7.7	100	889	75.9	68.9
	4	41	2	26	0	0	69	6.8	119	14.3	69	207	8.5	69	613	80.3	72.8
	5	38	0	43	0	1	82	8.1	171	22.3	82	229	9.7	82	729	137.5	124.8
	6	53	0	44	1	0	98	9.7	198	25.6	98	238	9.1	98	871	190.6	172.9
	7	208	0	198	2	0	408	40.4	211	28.0	408	241	10.3	408	3627	843.0	764.8
26 April	8	65	1	83	1	0	150	14.9	258	35.2	150	256	10.4	150	1333	378.8	343.7
	9	16	0	10	0	0	26	2.6	269	28.7	26	262	9.3	26	231	68.5	62.2
	10	27	1	15	0	0	43	4.3	278	36.0	43	261	8.9	43	382	117.0	106.2
	11	8	0	9	0	0	17	1.7	298	45.7	17	267	11.8	17	151	49.6	45.0
	12	6	0	3	0	0	9	0.9	298	50.6	9	270	12.6	9	80	26.3	23.9
	13	2	0	4	0	0	6	0.6	314	57.1	6	272	12.7	6	53	18.5	16.7
	14	2	0	0	0	0	2	0.2	313	15.6	2	269	2.1	2	18	6.1	5.6
	15																
	16																
Sample Total		532	10	462	5	1	1010	100.0	201	63.6	1010	236	24.4	1010	8979	1992.2	1807.3
Sex Composition		52.7	1.0	45.7	.5												
Unaged		31	0	39	1	0	71	7.0	229	54.0	71	245	18.9	71			
Sex Composition		43.7	.0	54.9	1.4												

Table 5.   Lower Cook Inlet intertidal herring egg survey transect and quadrat intervals, 1991.

Date	Area	Shore Line Length, L (m)	Total Number Transects n	Average Beach Width (m)	Quadrat Interval (m)	Total Number Quadrats m	Adjusted Mean No. Eggs/m2	Number of Surveyors
3 May	South Chenik Reef	1,500	12	375	10	448	798	4
16 May	South Chenik Reef	1,500	4	490	50	46	721	2
	Amakdedulia Cove	1,880	1	607	50	12	267	1
	East Chenik Reef	1,000	2	225	50	9	5,417	2
	Chenik Lagoon	1,676	2	373	100 & 112	31	2,809	2
24 May	Mallard Bay	500	4	713	10	285	578	2

Table 6. Herring biomass estimated from first spawn deposition survey of South Chenik Reef on 3 May, nine days after spawn observed on 24 April 1991.

Variable Symbol	Description	Equation No. in text	Value
L	shoreline length (m)	2	1,500
$\sqrt{0.1}$	transect strip width equal to quadrat width (m)	2	0.3162
N	total number of possible transects	2	4,743
	mean number of eggs per transect	4	954,384
T	total number of eggs (billions) in survey area	2	4.53
W	mean weight of herring in spawning population	9	200
F	estimated eggs/female	9	29,834
S	total biomass:female biomass ratio	10	2.12
B'	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 9 days	16	0.67
B	biomass (tonnes) required to deposited eggs	19	195
	spawnout rate		0.07
	total biomass (tonnes) at time of spawn		2,781
	lower 95% confidence limit of biomass estimate	20	824
	upper 95% confidence limit of biomass estimate	20	4,738

Table 7. Herring biomass estimated from second spawn deposition survey of South Chenik on 16 May, 22 days after spawn observed on 24 April 1991.

Variable Symbol	Description	Equation No. in text	Value
L	shoreline length (m)	2	1,880
$\sqrt{0.1}$	transect strip width equal to quadrat width (m)	2	0.3162
N	total number of possible transects	2	5,945
	mean number of eggs per transect	4	1,311,580
T	total number of eggs (billions) in survey area	2	7.80
W	mean weight of herring in spawning population	9	200
F	estimated eggs/female	9	29,834
S	total biomass:female biomass ratio	10	2.12
B'	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 22 days	16	0.39
B	biomass (tonnes) required to deposited eggs	19	181
	lower 95% confidence limit of biomass estimate	20	0
	upper 95% confidence limit of biomass estimate	20	347

Table 8.   Herring biomass estimated from spawn deposition survey of East Chenik on 16 May, four days
                after spawn observed on 12 May 1991.

Variable Symbol	Description	Equation No. in text	Value
N	total number of possible transects	2	3,162
$\sqrt{0.1}$	transect strip width equal to quadrat width (m)	2	0.3162
L	shoreline length (m)	2	1,000
$\hat{y}$	mean number of eggs per transect	4	3,854,511
T	total number of eggs (billions) in survey area	2	12.19
W	mean weight of herring in spawning population	9	200
F	estimated eggs/female	9	29,834
S	total biomass:female biomass ratio	10	2.12
B'	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 4 days	16	0.39
B	biomass (tonnes) required to deposited eggs	19	283
	lower 95% confidence limit of biomass estimate	20	0
	upper 95% confidence limit of biomass estimate	20	611

Table 9.   Herring biomass estimated from spawn deposition survey of Amakdedulia Cove on 16 May, four days
                after spawn observed on 12 May 1991.

Variable Symbol	Description	Equation No. in text	Value
w	mean transect length (m)	3	607
M	mean number possible quadrats within transect	3	1,920
	mean quadrate egg count	3	267
L	shoreline length (m)	2	1,880
$\sqrt{0.1}$	transect strip width equal to quadrat width (m)	2	0.3162
N	total number of possible transects	2	5,945
$\hat{y}$	mean number of eggs per transect	4	512,507
T	total number of eggs (billions) in survey area	2	3.05
W	mean weight of herring in spawning population	9	200
F	estimated eggs/female	9	29,834
S	total biomass:female biomass ratio	10	2.12
B'	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 4 days	16	0.39
B	biomass (tonnes) required to deposited eggs	19	71

19

Table 10.   Herring biomass estimated from spawn deposition survey of Chenik Lagoon on 16 May, four days after spawn observed on 12 May 1991.

Variable Symbol	Description	Equation No. in text	Value
L	shoreline length (m)	2	373
√0.1	transect strip width equal to quadrat width (m)	2	0.3162
N	total number of possible transects	2	1,180
ŷ	mean number of eggs per transect	4	14,946,368
T	total number of eggs (billions) in survey area	2	17.63
W	mean weight of herring in spawning population	9	200
F	estimated eggs/female	9	29,834
S	total biomass:female biomass ratio	10	2.12
B′	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 4 days	16	0.39
B	biomass (tonnes) required to deposited eggs	19	410
	lower 95% confidence limit of biomass estimate	20	0
	upper 95% confidence limit of biomass estimate	20	848

Table 11.   Herring biomass estimated from spawn deposition survey of Mallard Bay on 24 May of spawn observed between 12-24 May 1991.

Variable Symbol	Description	Equation No. in text	Value
L	shoreline length (m)	2	500
√0.1	transect strip width equal to quadrat width (m)	2	0.3162
N	total number of possible transects	2	1,581
ŷ	mean number of eggs per transect	4	1,301,467
T	total number of eggs (billions) in survey area	2	2.06
W	mean weight of herring in spawning population	9	138
F	estimated eggs/female	9	20,182
S	total biomass:female biomass ratio	10	2.05
B′	biomass (tonnes) to produce 1 billion eggs	10	14
R	egg loss after 6 days	16	0.52
B	biomass (tonnes) required to deposited eggs	19	60
	lower 95% confidence limit of biomass estimate	20	0
	upper 95% confidence limit of biomass estimate	20	150

20

Table 12.   Estimated intertidal herring egg loss from Equation 18.

Day	R
1	0.116
2	0.218
3	0.309
4	0.389
5	0.460
6	0.522
7	0.578
8	0.627
9	0.670
10	0.708
11	0.742
12	0.772
13	0.798
14	0.822
15	0.842
16	0.861
17	0.877
18	0.891
19	0.904
20	0.915
21	0.925
22	0.933

Table 13.   Variance Estimates for individual surveys[a].

	Source of Variation	Variance Estimate	S.D.
	3 May South Chenik Reef		
s_1^2	among transects	338,509	581.8
s_2^2	among quadrats	1,897,737	1,377.6
s_3^2	observer bias	3	1.8
Var(T)	total number of eggs	1	0.8
Var(F)	fecundity	43,730,165	6,612.9
Var(W)	mean weight	4,045	63.6
Var(B'|S)	biomass per billion eggs	20	4.5
Var(B|R)	spawning biomass	4,870	69.8
	16 May South Chenik Reef		
s_1^2	among transects	59,763	244.5
s_2^2	among quadrats	93,008	305.0
s_3^2	observer bias	32	5.7
Var(T)	total number of eggs	8	2.8
Var(F)	fecundity	43,730,165	6,612.9
Var(W)	mean weight	4,045	63.6
Var(B'|S)	biomass per billion eggs	20	4.5
Var(B|R)	spawning biomass	7,020	83.8
	16 May East Chenik Reef		
s_1^2	among transects	8,192,735	2,862.3
s_2^2	among quadrats	16,568,810	4,070.5
s_3^2	observer bias	555	23.6
Var(T)	total number of eggs	41	6.4
Var(F)	fecundity	43,730,165	6,612.9
Var(W)	mean weight	4,045	63.6
Var(B'|S)	biomass per billion eggs	20	4.5
Var(B|R)	spawning biomass	27,474	165.8
	16 May Chenik Lagoon		
s_1^2	among transects	100,337,094	10,016.8
s_2^2	among quadrats	2,575,481,709	50,749.2
s_3^2	observer bias	644	25.4
Var(T)	total number of eggs	70	8.4
Var(F)	fecundity	43,730,165	6,612.9
Var(W)	mean weight	4,045	63.6
Var(B'|S)	biomass per billion eggs	20	4.5
Var(B|R)	spawning biomass	50,058	223.7
	24 May Mallard Bay		
s_1^2	among transects	3,377,604	1,837.8
s_2^2	among quadrats	21,084,788	4,591.8
s_3^2	observer bias	17	4.1
Var(T)	total number of eggs	2	1.5
Var(F)	fecundity	20,011,818	4,473.5
Var(W)	mean weight	2,959	54.4
Var(B'|S)	biomass per billion eggs	31	5.5
Var(B|R)	spawning biomass	2,078	45.6

[a] Amakdedulia Cove had only one transect and therefore no variance estimate.

Lagoon

Chenik Head

no spawn seen in this area

Amakdedulia Cove

12

13   11

8   5

9   4   3   2

Kamishak Bay

1 km

Nordyke Island
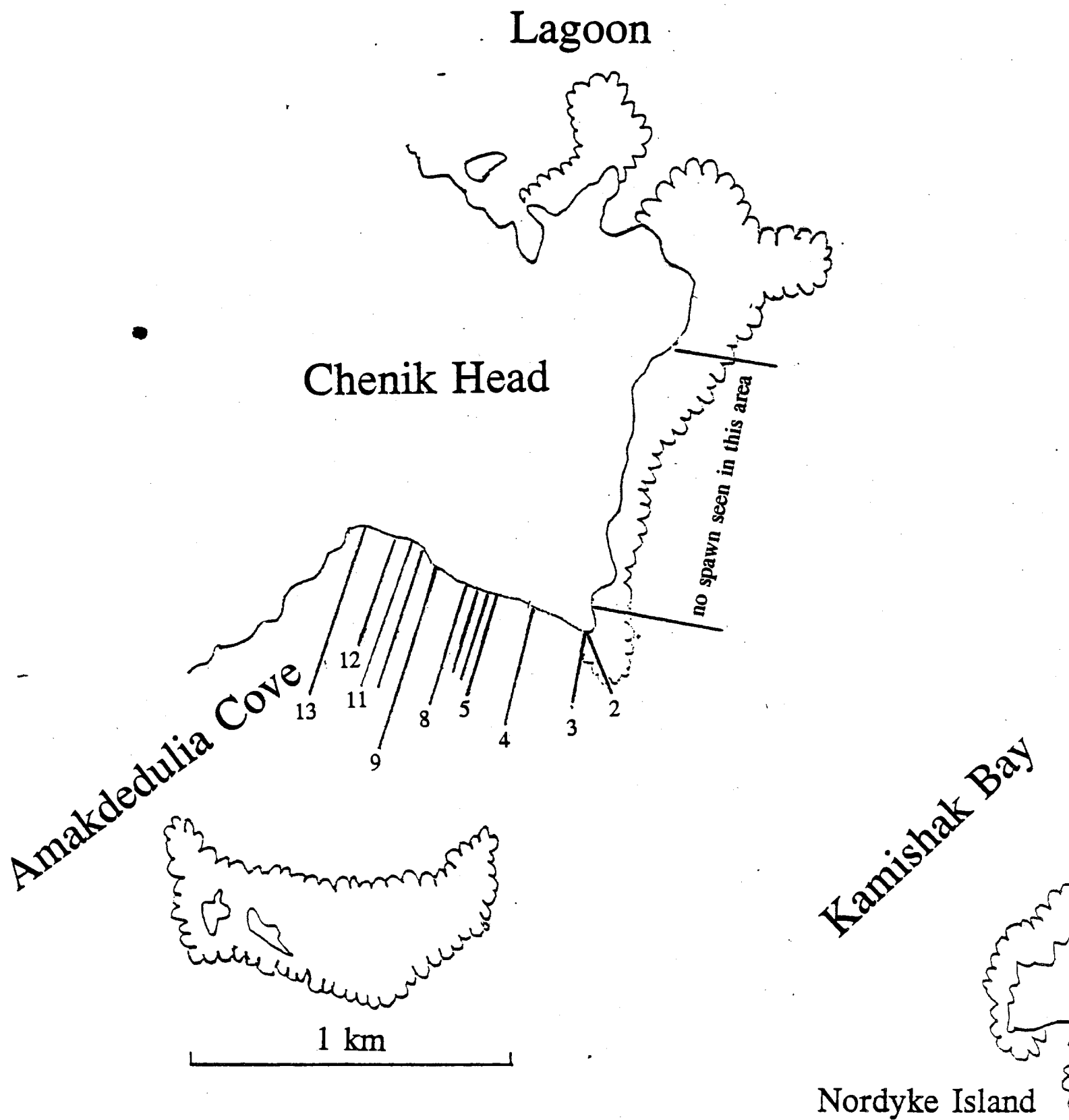
Figure 1. Chenik reef intertidal area surveyed for herring spawn on 3 May 1991.

Lagoon

Chenik Head

8 7

1

2

Amakdedulia Cove

4 3

6 5

Kamishak Bay

Nordyke Island

1 km
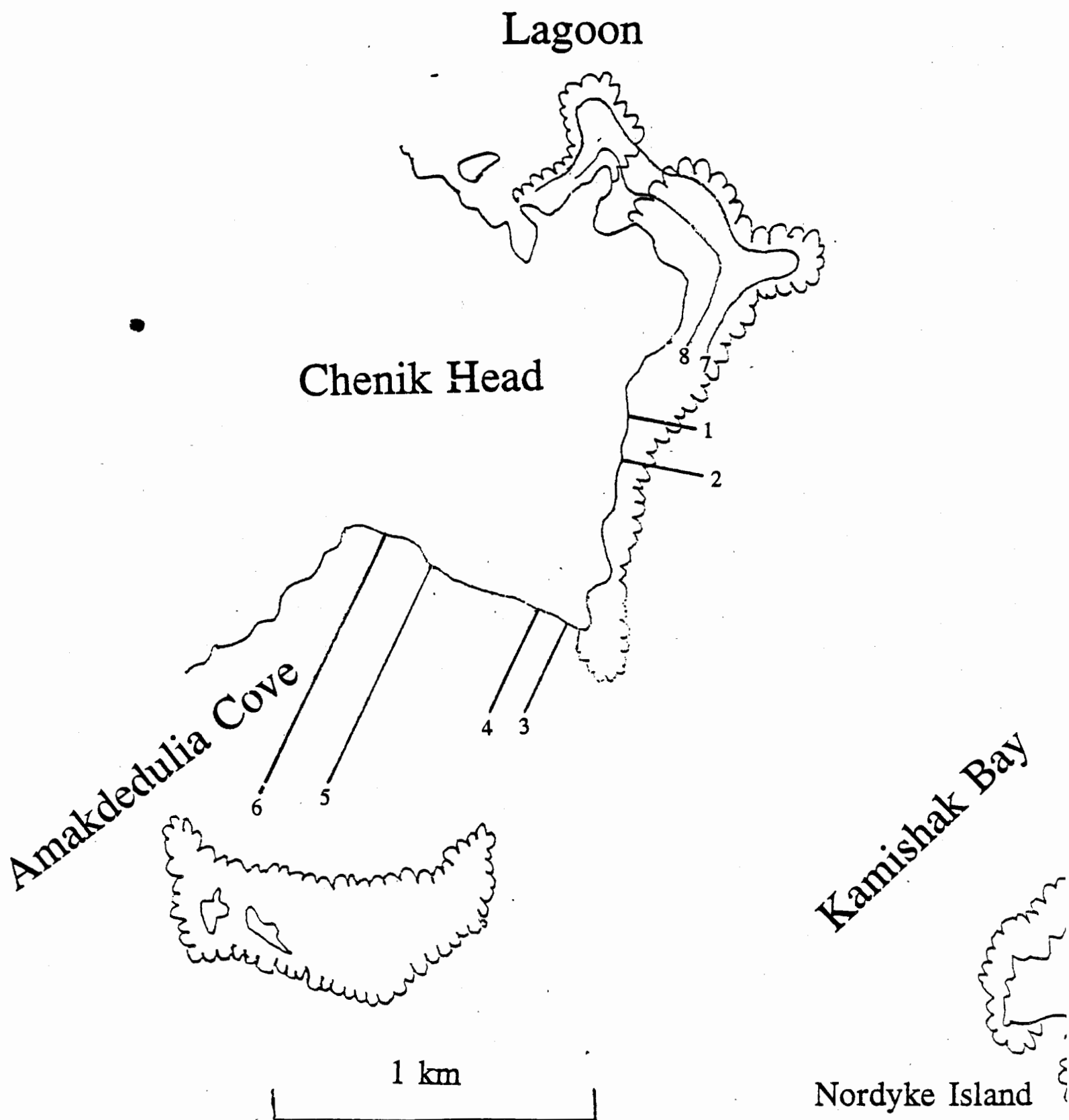
Figure 2. Amakdedulia Cove-Chenik Lagoon intertidal area surveyed for herring spawn on 3 May 1991.
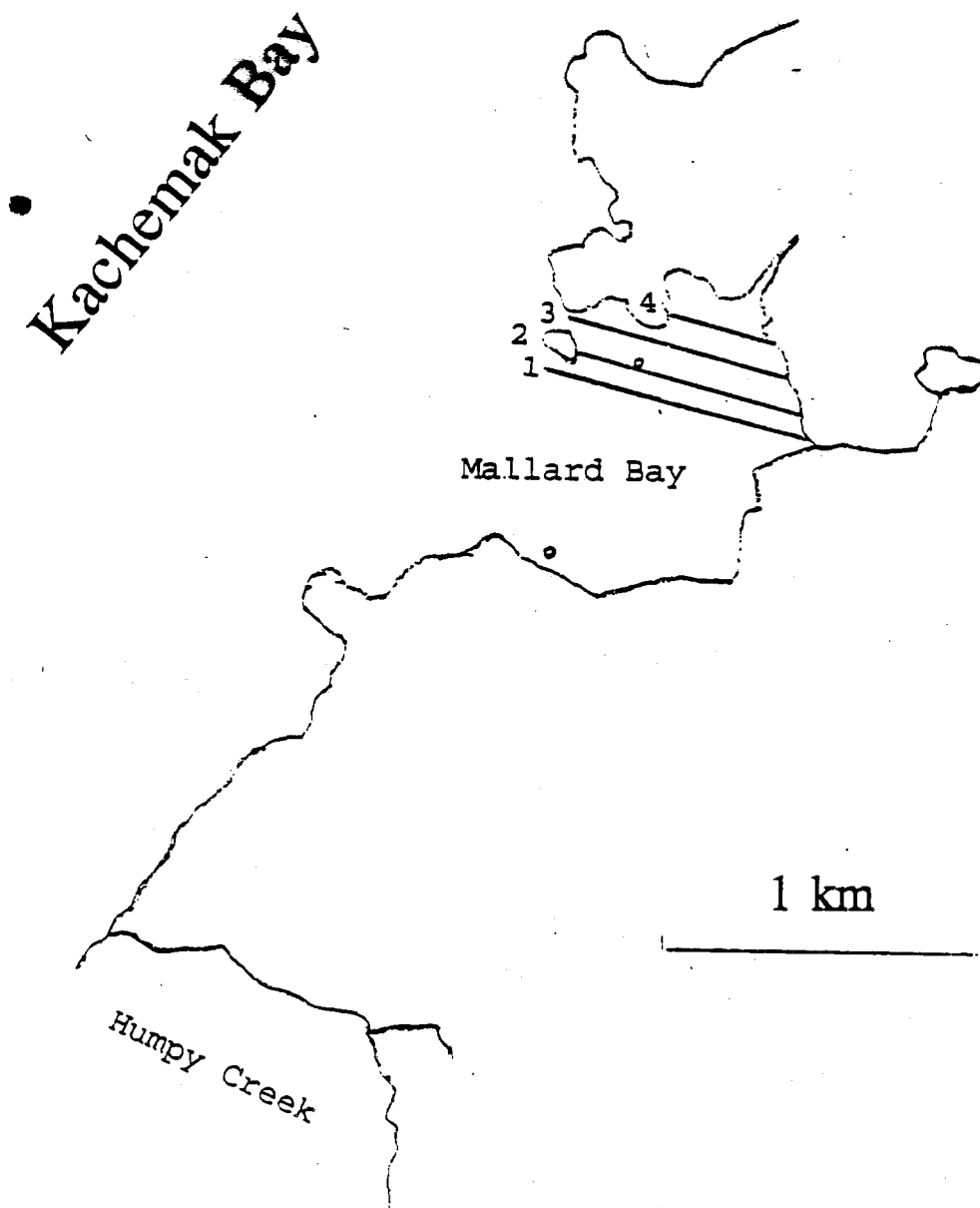
Figure 3. Mallard Bay intertidal area surveyed for herring spawn on 24 May 1991.
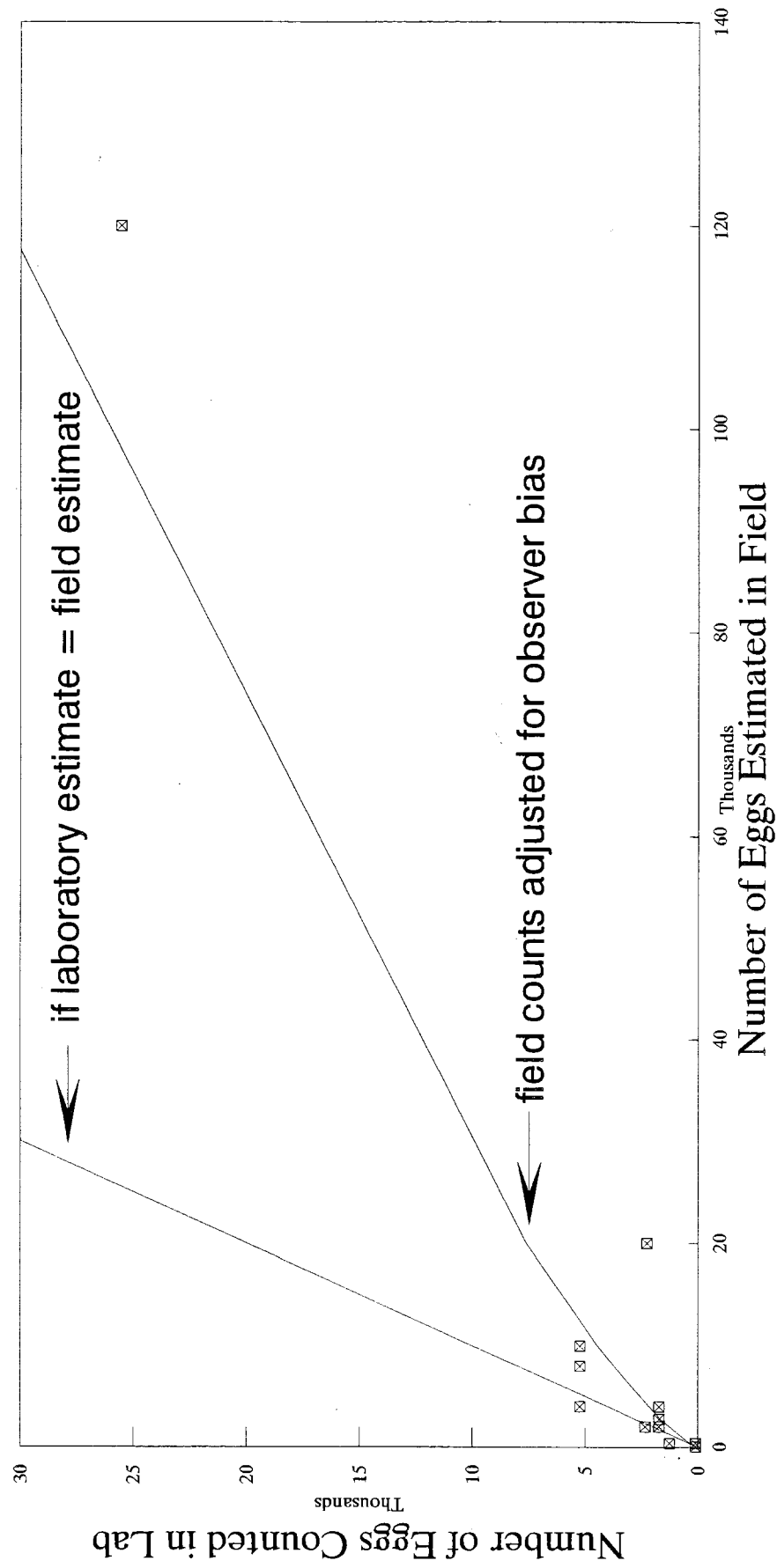
Figure 4. Observer bias in field estimates of herring egg densities.

$$\ln(F) = 4.790906 + 1.039448 \ln(W)$$

Herring Weight (g)

Number of Eggs (x 1,000)

Thousands
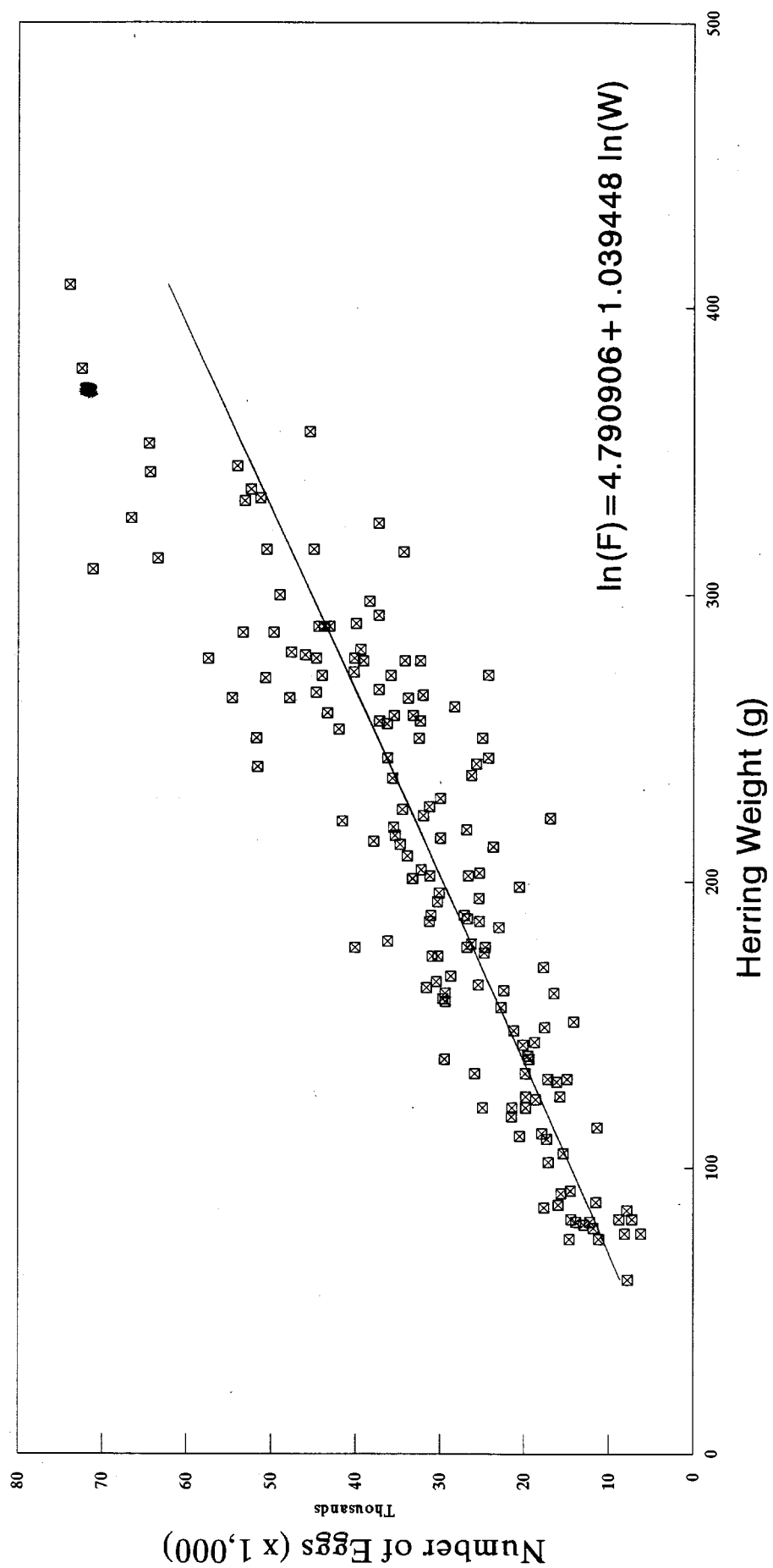
Figure 5. Relationship between herring weight and fecundity, Lower Cook Inlet, 1990 and 1991.
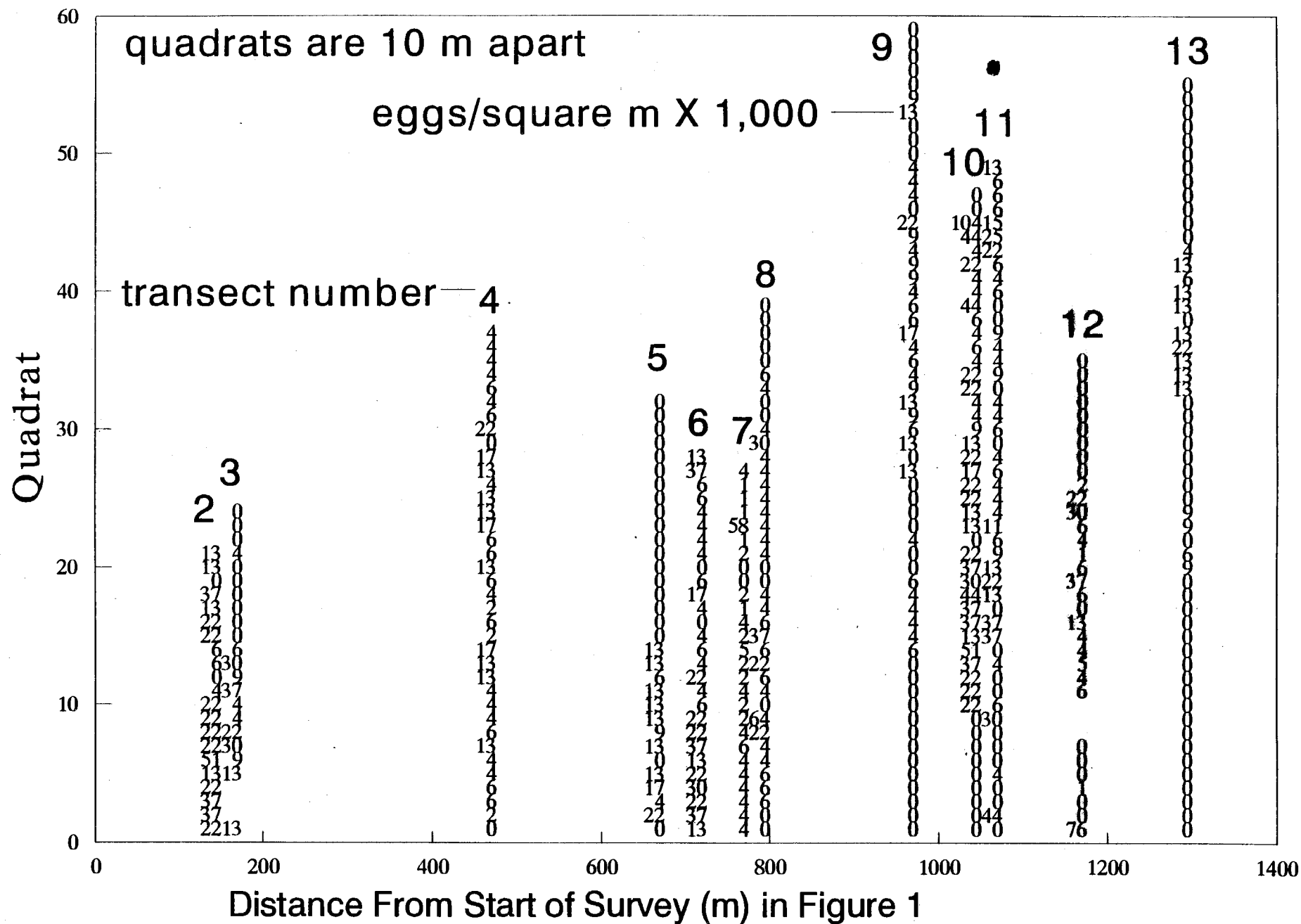
Figure 6. Egg density on south Chenik reef, 3 May 1991.
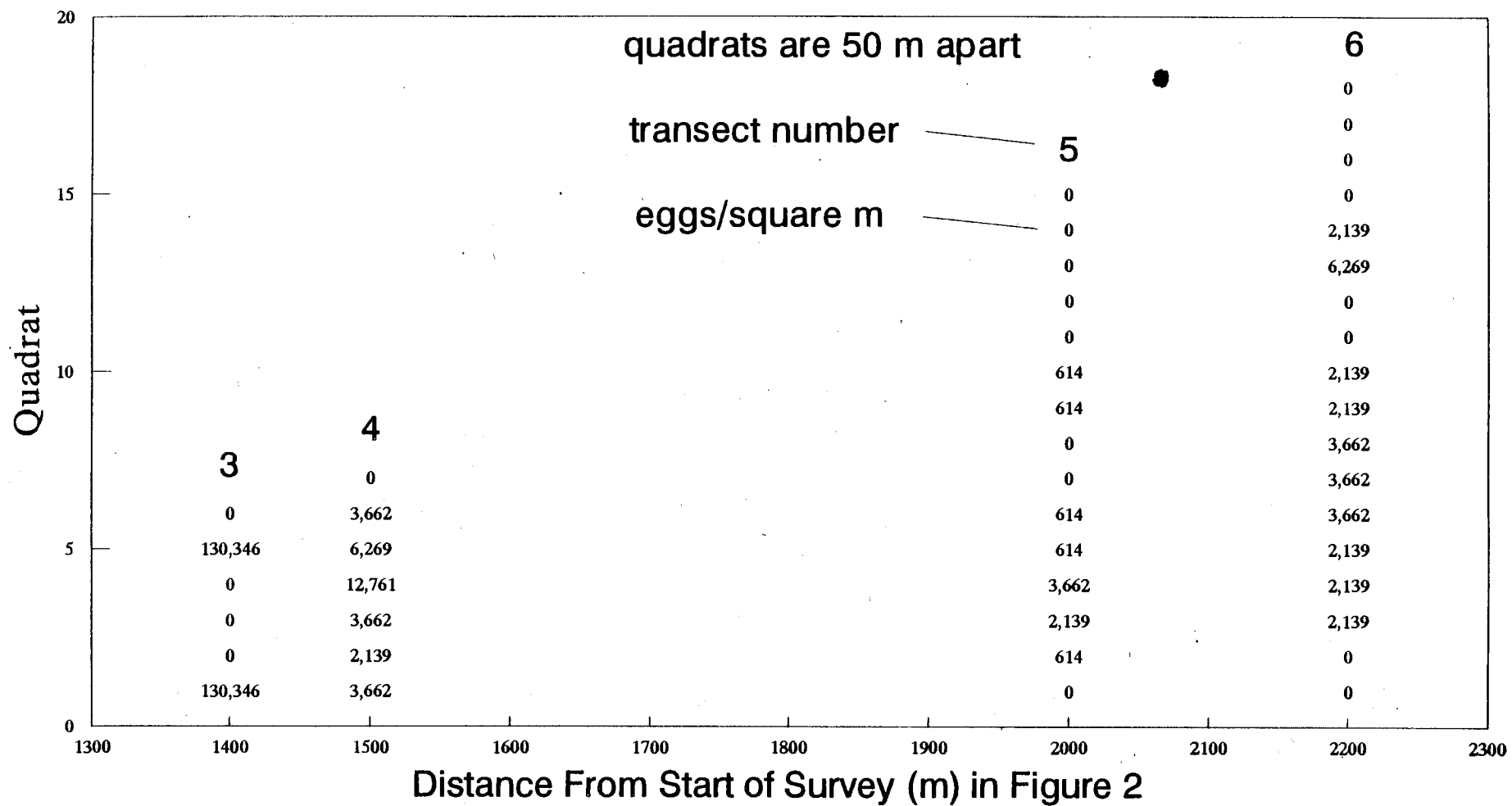
Figure 7. Egg density on south Chenik reef, 16 May 1991.
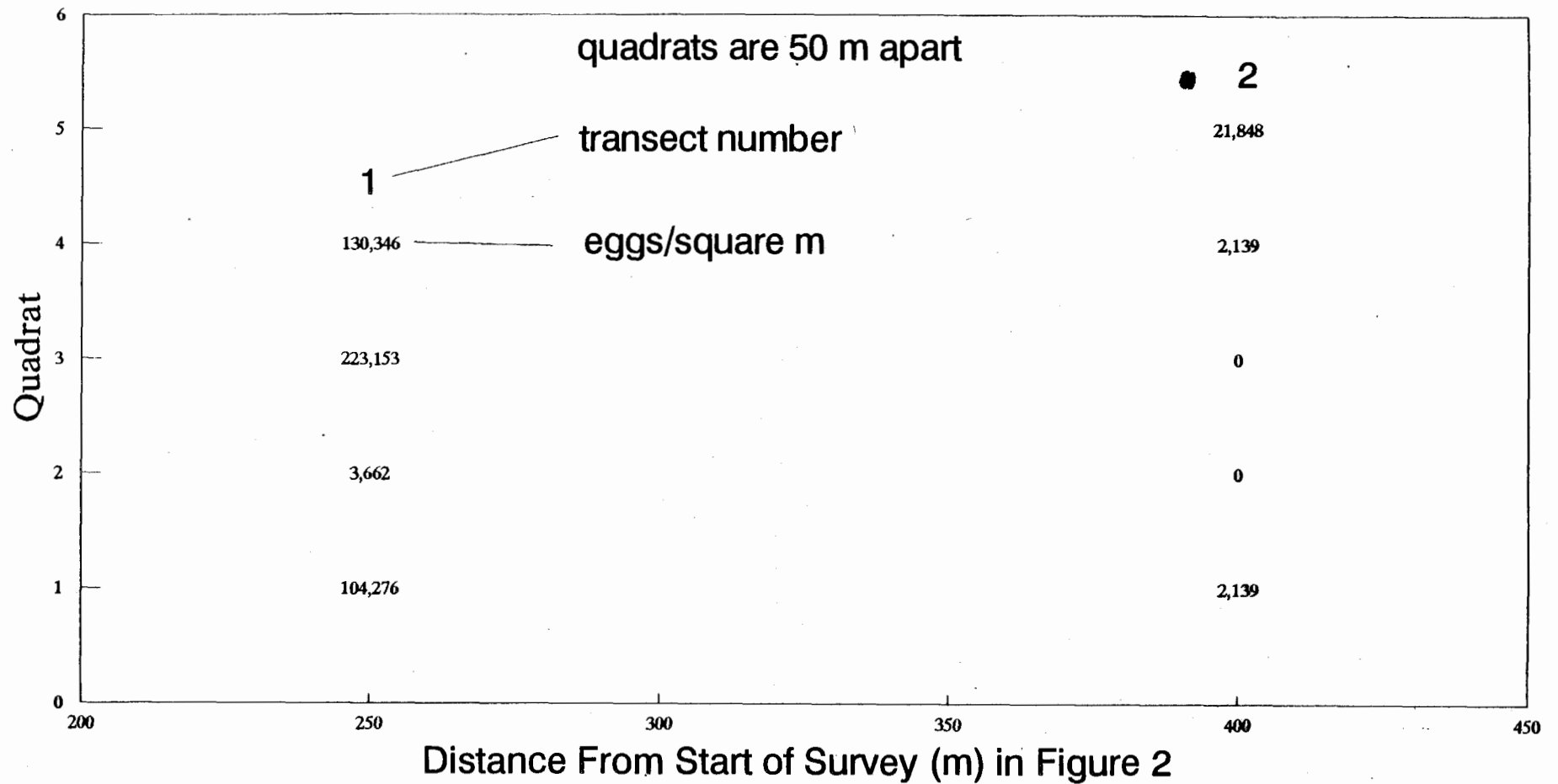
Figure 8. Egg density on east Chenik reef, 16 May 1991.
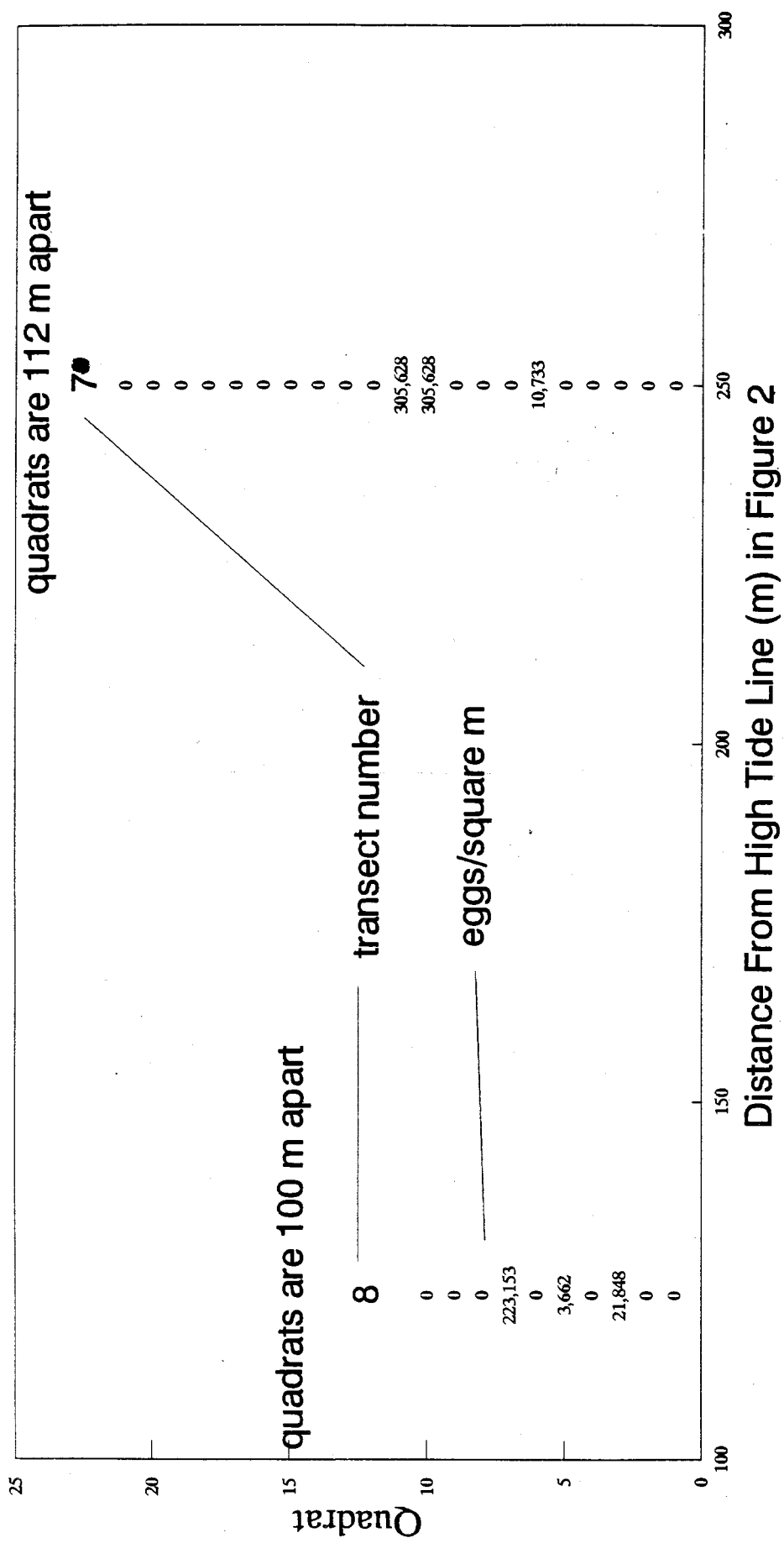
Figure 9. Egg density in Chenik Lagoon, 16 May 1991.

Figure 10. Egg density in Mallard Bay, 24 May 1991.

Appendix A.   Chenik reef intertidal spawn deposition survey data, 3 May 1991.

Transect No.	Quadrat	% Egg Cover	# Layers	Field Estimate (x)	Adjust for Observer Bias (y)	Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
2	1	0.100	1	4,000	2,185			
2	2	0.200	1	8,000	3,740			
2	3	0.200	1	8,000	3,740			
2	4	0.100	1	4,000	2,185			
2	5	0.050	1	2,000	1,276			
2	6	0.300	1	12,000	5,123			
2	7	0.100	1	4,000	2,185			
2	8	0.100	1	4,000	2,185			
2	9	0.100	1	4,000	2,185			
2	10	0.100	1	4,000	2,185			
2	11	0.010	1	400	366			
2	12	0.000	0	0	0			
2	13	0.020	1	800	627			
2	14	0.020	1	800	627			
2	15	0.100	1	4,000	2,185			
2	16	0.100	1	4,000	2,185			
2	17	0.050	1	2,000	1,276			
2	18	0.200	1	8,000	3,740			
2	19	0.000	0	0	0			
2	20	0.050	1	2,000	1,276			
2	21	0.050	1	2,000	1,276	1,931	664	1,282,200
3	1	0.050	1	2,000	1,276			
3	5	0.050	1	2,000	1,276			
3	6	0.030	1	1,200	859			
3	7	0.150	1	6,000	2,992			
3	8	0.100	1	4,000	2,185			
3	9	0.010	1	400	366			
3	10	0.010	1	400	366			
3	11	0.200	1	8,000	3,740			
3	12	0.030	1	1,200	859			
3	13	0.150	1	6,000	2,992			
3	14	0.020	1	800	627			
3	15	0.000	0	0	0			
3	16	0.000	0	0	0			
3	17	0.000	0	0	0			
3	18	0.000	0	0	0			
3	19	0.000	0	0	0			
3	20	0.000	0	0	0			
3	21	0.010	1	400	366			
3	22	0.000	0	0	0			
3	23	0.000	0	0	0			
3	24	0.000	0	0	0	853	759	647,085
4	1	0.000	0	0	0			
4	2	0.005	1	200	214			
4	3	0.020	1	800	627			
4	4	0.020	1	800	627			

-Continued-

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| Transect No. | Quadrat | % Egg Cover | # Layers | Number of Eggs in Quadrat | | Mean Quadrat Egg Count within Transect $(\bar{y})$ | Total Possible Quadrats within M | Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$ |
				Field Estimate (x)	Adjust for Observer Bias (y)			
4	5	0.010	1	400	366			
4	6	0.010	1	400	366			
4	7	0.050	1	2,000	1,276			
4	8	0.020	1	800	627			
4	9	0.010	1	400	366			
4	10	0.010	1	400	366			
4	11	0.010	1	400	366			
4	12	0.050	1	2,000	1,276			
4	13	0.050	1	2,000	1,276			
4	14	0.070	1	2,800	1,657			
4	15	0.005	1	200	214			
4	16	0.020	1	800	627			
4	17	0.005	1	200	214			
4	18	0.010	1	400	366			
4	19	0.020	1	800	627			
4	20	0.050	1	2,000	1,276			
4	21	0.020	1	800	627			
4	22	0.020	1	800	627			
4	23	0.070	1	2,800	1,657			
4	24	0.050	1	2,000	1,276			
4	25	0.050	1	2,000	1,276			
4	26	0.010	1	400	366			
4	27	0.050	1	2,000	1,276			
4	28	0.070	1	2,800	1,657			
4	29	0.000	0	0	0			
4	30	0.100	1	4,000	2,185			
4	31	0.020	1	800	627			
4	32	0.010	1	400	366			
4	33	0.020	1	800	627			
4	34	0.010	1	400	366			
4	35	0.010	1	400	366			
4	36	0.010	1	400	366			
4	37	0.010	1	400	366	723	1,170	846,432
5	1	0.000	0	0	0			
5	2	0.100	1	4,000	2,185			
5	3	0.010	1	400	366			
5	4	0.070	1	2,800	1,657			
5	5	0.050	1	2,000	1,276			
5	6	0.000	0	0	0			
5	7	0.050	1	2,000	1,276			
5	8	0.030	1	1,200	859			
5	9	0.050	1	2,000	1,276			
5	10	0.050	1	2,000	1,276			
5	11	0.050	1	2,000	1,276			
5	12	0.020	1	800	627			
5	13	0.050	1	2,000	1,276			
5	14	0.050	1	2,000	1,276			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
5	15	0.000	0	0	0			
5	16	0.000	0	0	0			
5	17	0.000	0	0	0			
5	18	0.000	0	0	0			
5	19	0.000	0	0	0			
5	20	0.000	0	0	0			
5	21	0.000	0	0	0			
5	22	0.000	0	0	0			
5	23	0.000	0	0	0			
5	24	0.000	0	0	0			
5	25	0.000	0	0	0			
5	26	0.000	0	0	0			
5	27	0.000	0	0	0			
5	28	0.000	0	0	0			
5	29	0.000	0	0	0			
5	30	0.000	0	0	0			
5	31	0.000	0	0	0			
5	32	0.000	0	0	0	457	1,012	462,525
6	1	0.050	1	2,000	1,276			
6	2	0.200	1	8,000	3,740			
6	3	0.100	1	4,000	2,185			
6	4	0.150	1	6,000	2,992			
6	5	0.100	1	4,000	2,185			
6	6	0.050	1	2,000	1,276			
6	7	0.200	1	8,000	3,740			
6	8	0.100	1	4,000	2,185			
6	9	0.100	1	4,000	2,185			
6	10	0.020	1	800	627			
6	11	0.010	1	400	366			
6	12	0.100	1	4,000	2,185			
6	13	0.010	1	400	366			
6	14	0.020	1	800	627			
6	15	0.010	1	400	366			
6	16	0.000	0	0	0			
6	17	0.010	1	400	366			
6	18	0.070	1	2,800	1,657			
6	19	0.020	1	800	627			
6	20	0.000	0	0	0			
6	21	0.010	1	400	366			
6	22	0.010	1	400	366			
6	23	0.010	1	400	366			
6	24	0.010	1	400	366			
6	25	0.020	1	800	627			
6	26	0.020	1	800	627			
6	27	0.200	1	8,000	3,740			
6	28	0.050	1	2,000	1,276	1,310	885	1,160,134
7	1	0.010	1	400	366			

-Continued-

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$)
				Field Estimate (x)	Adjust for Observer Bias (y)			
7	2	0.010	1	400	366			
7	3	0.010	1	400	366			
7	4	0.010	1	400	366			
7	5	0.010	1	400	366			
7	6	0.010	1	400	366			
7	7	0.020	1	800	627			
7	8	0.010	1	400	366			
7	9	0.005	1	200	214			
7	10	0.005	1	200	214			
7	11	0.010	1	400	366			
7	12	0.005	1	200	214			
7	13	0.005	1	200	214			
7	14	0.015	1	600	502			
7	15	0.005	1	200	214			
7	16	0.010	1	400	366			
7	17	0.003	1	100	125			
7	18	0.005	1	200	214			
7	19	0.000	0	0	0			
7	20	0.000	0	0	0			
7	21	0.005	1	200	214			
7	22	0.003	1	100	125			
7	23	0.350	1	14,000	5,773			
7	24	0.003	1	100	125			
7	25	0.003	1	100	125			
7	26	0.003	1	100	125			
7	27	0.010	1	400	366	470	854	401,164
8	1	0.000	0	0	0			
8	2	0.000	0	0	0			
8	3	0.020	1	800	627			
8	4	0.020	1	800	627			
8	5	0.020	1	800	627			
8	6	0.010	1	400	366			
8	7	0.010	1	400	366			
8	8	0.100	1	4,000	2,185			
8	9	0.400	1	16,000	6,404			
8	10	0.000	0	0	0			
8	11	0.010	1	400	366			
8	12	0.020	1	800	627			
8	13	0.100	1	4,000	2,185			
8	14	0.020	1	800	627			
8	15	0.200	1	8,000	3,740			
8	16	0.020	1	800	627			
8	17	0.010	1	400	366			
8	18	0.010	1	400	366			
8	19	0.000	0	0	0			
8	20	0.000	0	0	0			
8	21	0.010	1	400	366			
8	22	0.010	1	400	366			

-Continued-

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
8	23	0.010	1	400	366			
8	24	0.010	1	400	366			
8	25	0.010	1	400	366			
8	26	0.010	1	400	366			
8	27	0.010	1	400	366			
8	28	0.010	1	400	366			
8	29	0.150	1	6,000	2,992			
8	30	0.010	1	400	366			
8	31	0.000	0	0	0			
8	32	0.000	0	0	0			
8	33	0.010	1	400	366			
8	34	0.020	1	800	627			
8	35	0.000	0	0	0			
8	36	0.000	0	0	0			
8	37	0.000	0	0	0			
8	38	0.000	0	0	0			
8	39	0.000	0	0	0	702	1,233	866,061
9	1	0.000	0	0	0			
9	2	0.000	0	0	0			
9	3	0.000	0	0	0			
9	4	0.000	0	0	0			
9	5	0.000	0	0	0			
9	6	0.000	0	0	0			
9	7	0.000	0	0	0			
9	8	0.000	0	0	0			
9	9	0.000	0	0	0			
9	10	0.000	0	0	0			
9	11	0.000	0	0	0			
9	12	0.000	0	0	0			
9	13	0.000	0	0	0			
9	14	0.020	1	800	627			
9	15	0.010	1	400	366			
9	16	0.010	1	400	366			
9	17	0.010	1	400	366			
9	18	0.010	1	400	366			
9	19	0.020	1	800	627			
9	20	0.000	0	0	0			
9	21	0.000	0	0	0			
9	22	0.010	1	400	366			
9	23	0.000	0	0	0			
9	24	0.000	0	0	0			
9	25	0.000	0	0	0			
9	26	0.000	0	0	0			
9	27	0.050	1	2,000	1,276			
9	28	0.000	0	0	0			
9	29	0.050	1	2,000	1,276			
9	30	0.020	1	800	627			
9	31	0.030	1	1,200	859			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat Field Estimate (x)	Adjust for Observer Bias (y)	Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect (M$\bar{y}$)
9	32	0.050	1	2,000	1,276			
9	33	0.030	1	1,200	859			
9	34	0.010	1	400	366			
9	35	0.020	1	800	627			
9	36	0.010	1	400	366			
9	37	0.070	1	2,800	1,657			
9	38	0.020	1	800	627			
9	39	0.020	1	800	627			
9	40	0.010	1	400	366			
9	41	0.030	1	1,200	859			
9	42	0.030	1	1,200	859			
9	43	0.010	1	400	366			
9	44	0.030	1	1,200	859			
9	45	0.100	1	4,000	2,185			
9	46	0.000	0	0	0			
9	47	0.010	1	400	366			
9	48	0.010	1	400	366			
9	49	0.010	1	400	366			
9	50	0.000	0	0	0			
9	51	0.000	0	0	0			
9	52	0.000	0	0	0			
9	53	0.050	1	2,000	1,276			
9	54	0.030	1	1,200	859			
9	55	0.000	0	0	0			
9	56	0.000	0	0	0			
9	57	0.000	0	0	0			
9	58	0.000	0	0	0			
9	59	0.000	0	0	0			
9	60	0.000	0	0	0	371	1,897	703,734
10	1	0.000	0	0	0			
10	2	0.000	0	0	0			
10	3	0.000	0	0	0			
10	4	0.000	0	0	0			
10	5	0.000	0	0	0			
10	6	0.000	0	0	0			
10	7	0.000	0	0	0			
10	8	0.000	0	0	0			
10	9	0.000	0	0	0			
10	10	0.100	1	4,000	2,185			
10	11	0.100	1	4,000	2,185			
10	12	0.100	1	4,000	2,185			
10	13	0.200	1	8,000	3,740			
10	14	0.300	1	12,000	5,123			
10	15	0.050	1	2,000	1,276			
10	16	0.200	1	8,000	3,740			
10	17	0.200	1	8,000	3,740			
10	18	0.250	1	10,000	4,447			
10	19	0.150	1	6,000	2,992			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
10	20	0.200	1	8,000	3,740			
10	21	0.100	1	4,000	2,185			
10	22	0.000	0	0	0			
10	23	0.050	1	2,000	1,276			
10	24	0.050	1	2,000	1,276			
10	25	0.100	1	4,000	2,185			
10	26	0.100	1	4,000	2,185			
10	27	0.070	1	2,800	1,657			
10	28	0.100	1	4,000	2,185			
10	29	0.050	1	2,000	1,276			
10	30	0.030	1	1,200	859			
10	31	0.010	1	400	366			
10	32	0.010	1	400	366			
10	33	0.100	1	4,000	2,185			
10	34	0.100	1	4,000	2,185			
10	35	0.010	1	400	366			
10	36	0.020	1	800	627			
10	37	0.010	1	400	366			
10	38	0.020	1	800	627			
10	39	0.250	1	10,000	4,447			
10	40	0.010	1	400	366			
10	41	0.010	1	400	366			
10	42	0.100	1	4,000	2,185			
10	43	0.010	1	400	366			
10	44	0.250	1	10,000	4,447			
10	45	0.750	1	30,000	10,428			
10	46	0.000	0	0	0			
10	47	0.000	0	0	0	1,705	1,486	2,533,951
11	1	0.000	0	0	0			
11	2	0.250	1	10,000	4,447			
11	3	0.000	0	0	0			
11	4	0.000	0	0	0			
11	5	0.010	1	400	366			
11	6	0.000	0	0	0			
11	7	0.000	0	0	0			
11	8	0.000	0	0	0			
11	9	0.150	1	6,000	2,992			
11	10	0.020	1	800	627			
11	11	0.000	0	0	0			
11	12	0.000	0	0	0			
11	13	0.010	1	400	366			
11	14	0.000	0	0	0			
11	15	0.200	1	8,000	3,740			
11	16	0.200	1	8,000	3,740			
11	17	0.000	0	0	0			
11	18	0.050	1	2,000	1,276			
11	19	0.100	1	4,000	2,185			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
11	20	0.050	1	2,000	1,276			
11	21	0.030	1	1,200	859			
11	22	0.020	1	800	627			
11	23	0.040	1	1,600	1,073			
11	24	0.010	1	400	366			
11	25	0.010	1	400	366			
11	26	0.010	1	400	366			
11	27	0.020	1	800	627			
11	28	0.010	1	400	366			
11	29	0.000	0	0	0			
11	30	0.020	1	800	627			
11	31	0.010	1	400	366			
11	32	0.010	1	400	366			
11	33	0.000	0	0	0			
11	34	0.030	1	1,200	859			
11	35	0.010	1	400	366			
11	36	0.010	1	400	366			
11	37	0.030	1	1,200	859			
11	38	0.000	0	0	0			
11	39	0.000	0	0	0			
11	40	0.020	1	800	627			
11	41	0.010	1	400	366			
11	42	0.020	1	800	627			
11	43	0.100	1	4,000	2,185			
11	44	0.120	1	4,800	2,517			
11	45	0.060	1	2,400	1,470			
11	46	0.020	1	800	627			
11	47	0.020	1	800	627			
11	48	0.020	1	800	627			
11	49	0.050	1	2,000	1,276	825	1,550	1,278,342
12	1	0.500	1	20,000	7,614			
12	2	0.000	0	0	0			
12	3	0.000	0	0	0			
12	4	0.003	1	100	125			
12	5	0.000	0	0	0			
12	6	0.000	0	0	0			
12	7	0.000	0	0	0			
12	11	0.020	1	800	627			
12	12	0.010	1	400	366			
12	13	0.015	1	600	502			
12	14	0.010	1	400	366			
12	15	0.010	1	400	366			
12	16	0.050	1	2,000	1,276			
12	17	0.000	0	0	0			
12	18	0.020	1	800	627			
12	19	0.200	1	8,000	3,740			
12	20	0.020	1	800	627			
12	21	0.003	1	100	125			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$)
				Field Estimate (x)	Adjust for Observer Bias (y)			
12	22	0.010	1	400	366			
12	23	0.020	1	800	627			
12	24	0.150	1	6,000	2,992			
12	25	0.100	1	4,000	2,185			
12	26	0.005	1	200	214			
12	27	0.000	0	0	0			
12	28	0.000	0	0	0			
12	29	0.000	0	0	0			
12	30	0.000	0	0	0			
12	31	0.000	0	0	0			
12	32	0.000	0	0	0			
12	33	0.000	0	0	0			
12	34	0.000	0	0	0			
12	35	0.000	0	0	0	711	1,107	786,691
13	1	0.000	0	0	0			
13	2	0.000	0	0	0			
13	3	0.000	0	0	0			
13	4	0.000	0	0	0			
13	5	0.000	0	0	0			
13	6	0.000	0	0	0			
13	7	0.000	0	0	0			
13	8	0.000	0	0	0			
13	9	0.000	0	0	0			
13	10	0.000	0	0	0			
13	11	0.000	0	0	0			
13	12	0.000	0	0	0			
13	13	0.000	0	0	0			
13	14	0.000	0	0	0			
13	15	0.000	0	0	0			
13	16	0.000	0	0	0			
13	17	0.000	0	0	0			
13	18	0.000	0	0	0			
13	19	0.000	0	0	0			
13	20	0.030	1	1,200	859			
13	21	0.020	1	800	627			
13	22	0.000	0	0	0			
13	23	0.030	1	1,200	859			
13	24	0.030	1	1,200	859			
13	25	0.000	0	0	0			
13	26	0.000	0	0	0			
13	27	0.000	0	0	0			
13	28	0.000	0	0	0			
13	29	0.000	0	0	0			
13	30	0.000	0	0	0			
13	31	0.000	0	0	0			
13	32	0.000	0	0	0			
13	33	0.050	1	2,000	1,276			
13	34	0.050	1	2,000	1,276			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$)
				Field Estimate (x)	Adjust for Observer Bias (y)			
13	35	0.050	1	2,000	1,276			
13	36	0.100	1	4,000	2,185			
13	37	0.050	1	2,000	1,276			
13	38	0.000	0	0	0			
13	39	0.050	1	2,000	1,276			
13	40	0.050	1	2,000	1,276			
13	41	0.020	1	800	627			
13	42	0.050	1	2,000	1,276			
13	43	0.010	1	400	366			
13	44	0.000	0	0	0			
13	45	0.000	0	0	0			
13	46	0.000	0	0	0			
13	47	0.000	0	0	0			
13	48	0.000	0	0	0			
13	49	0.000	0	0	0			
13	50	0.000	0	0	0			
13	51	0.000	0	0	0			
13	52	0.000	0	0	0			
13	53	0.000	0	0	0			
13	54	0.000	0	0	0			
13	55	0.000	0	0	0	278	1,739	484,266
Mean					798			954,382

Note: 10 m quadrat interval

Appendix B.   East Chenik reef intertidal spawn deposition survey data, 16 May 1991.

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$)
				Field Estimate (x)	Adjust for Observer Bias (y)			
1	1	0.250	3	30,000	10,428			
1	2	0.010	1	400	366			
1	3	1.000	2	80,000	22,315			
1	4	1.000	1	40,000	13,035	11,536	632	7,295,937
2	1	0.005	1	200	214			
2	2	0.000	0	0	0			
2	3	0.000	0	0	0			
2	4	0.005	1	200	214			
2	5	0.050	2	4,000	2,185	523	791	413,085
mean					5,417			3,854,511

Note: 50 m quadrat interval.

Appendix C.   South Chenik reef intertidal spawn deposition survey data, 16 May 1991.

| Transect No. | Quadrat | % Egg Cover | # Layers | Number of Eggs in Quadrat | | Mean Quadrat Egg Count within Transect ($\bar{y}$) | Total Possible Quadrats within M | Estimated Number of Eggs Within Transect ($M\bar{y}$) |
				Field Estimate (x)	Adjust for Observer Bias (y)			
3	1	1.000	1	40,000	13,035			
3	2	0.000	0	0	0			
3	3	0.000	0	0	0			
3	4	0.000	0	0	0			
3	5	1.000	1	40,000	13,035			
3	6	0.000	0	0	0	4,345	949	4,121,887
4	1	0.010	1	400	366			
4	2	0.005	1	200	214			
4	3	0.010	1	400	366			
4	4	0.050	1	2,000	1,276			
4	5	0.020	1	800	627			
4	6	0.010	1	400	366			
4	7	0.000	0	0	0	459	1,107	508,429
5	1	0.000	0	0	0			
5	2	0.001	1	40	61			
5	3	0.005	1	200	214			
5	4	0.010	1	400	366			
5	5	0.001	1	40	61			
5	6	0.001	1	40	61			
5	7	0.000	0	0	0			
5	8	0.000	0	0	0			
5	9	0.001	1	40	61			
5	10	0.001	1	40	61			
5	11	0.000	0	0	0			
5	12	0.000	0	0	0			
5	13	0.000	0	0	0			
5	14	0.000	0	0	0			
5	15	0.000	0	0	0	59	2,372	140,247
6	1	0.000	0	0	0			
6	2	0.000	0	0	0			
6	3	0.005	1	200	214			
6	4	0.005	1	200	214			
6	5	0.005	1	200	214			
6	6	0.010	1	400	366			
6	7	0.010	1	400	366			
6	8	0.010	1	400	366			
6	9	0.005	1	200	214			
6	10	0.005	1	200	214			
6	11	0.000	0	0	0			
6	12	0.000	0	0	0			
6	13	0.020	1	800	627			
6	14	0.005	1	200	214			
6	15	0.000	0	0	0			
6	16	0.000	0	0	0			
6	17	0.000	0	0	0			
6	18	0.000	0	0	0	167	2,846	475,755
Mean					721			1,311,580

Note: 50 m quadrat interval.

Appendix D.   Chenik lagoon intertidal spawn deposition survey data, 16 May 1991.

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat Field Estimate (x)	Adjust for Observer Bias (y)	Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Within Transect (M$\bar{y}$)
7	1	0.000	0	0	0			
7	2	0.000	0	0	0			
7	3	0.000	0	0	0			
7	4	0.000	0	0	0			
7	5	0.000	0	0	0			
7	6	0.020	2	1,600	1,073			
7	7	0.000	0	0	0			
7	8	0.000	0	0	0			
7	9	0.000	0	0	0			
7	10	1.000	3	120,000	30,563			
7	11	1.000	3	120,000	30,563			
7	12	0.000	0	0	0			
7	13	0.000	0	0	0			
7	14	0.000	0	0	0			
7	15	0.000	0	0	0			
7	16	0.000	0	0	0			
7	17	0.000	0	0	0			
7	18	0.000	0	0	0			
7	19	0.000	0	0	0			
7	20	0.000	0	0	0			
7	21	0.000	0	0	0	2,962	7,438	22,029,344
8	1	0.000	0	0	0			
8	2	0.000	0	0	0			
8	3	0.100	1	4,000	2,185			
8	4	0.000	0	0	0			
8	5	0.010	1	400	366			
8	6	0.000	0	0	0			
8	7	1.000	2	80,000	22,315			
8	8	0.000	0	0	0			
8	9	0.000	0	0	0			
8	10	0.000	0	0	0	2,487	3,162	7,863,392
Mean					2,809			14,946,368

Note: 112 m quadrat interval for transect 7 and 100 m quadrat interval for transect 8.

Appendix E.   Mallard Bay intertidal spawn deposition survey data, 24 May 1991.

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat Field Estimate (x)	Adjust for Observer Bias (y)	Mean Quadrat Egg Count within Transect (ȳ)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect (Mȳ)
1	1	0.000	0	0	0			
1	2	0.000	0	0	0			
1	3	0.000	0	0	0			
1	4	0.000	0	0	0			
1	5	0.000	0	0	0			
1	6	0.000	0	0	0			
1	7	0.000	0	0	0			
1	8	0.000	0	0	0			
1	9	0.000	0	0	0			
1	10	0.000	0	0	0			
1	11	0.000	0	0	0			
1	12	0.000	0	0	0			
1	13	0.000	0	0	0			
1	14	0.000	0	0	0			
1	15	0.000	0	0	0			
1	16	0.000	0	0	0			
1	17	0.000	0	0	0			
1	18	0.000	0	0	0			
1	19	0.000	0	0	0			
1	20	0.000	0	0	0			
1	21	0.000	0	0	0			
1	22	0.000	0	0	0			
1	23	0.000	0	0	0			
1	24	0.000	0	0	0			
1	25	0.000	0	0	0			
1	26	0.000	0	0	0			
1	27	0.000	0	0	0			
1	28	0.000	0	0	0			
1	29	0.000	0	0	0			
1	30	0.000	0	0	0			
1	31	0.000	0	0	0			
1	32	0.000	0	0	0			
1	33	1.000	1	40,000	13,035			
1	34	0.005	1	200	214			
1	35	0.000	0	0	0			
1	36	0.000	0	0	0			
1	37	0.005	1	200	214			
1	38	0.000	0	0	0			
1	39	0.005	1	200	214			
1	40	0.010	1	400	366			
1	41	0.000	0	0	0			
1	42	0.005	1	200	214			
1	43	0.005	1	200	214			
1	44	0.000	0	0	0			
1	45	0.000	0	0	0			
1	46	0.000	0	0	0			
1	47	0.000	0	0	0			
1	48	0.000	0	0	0			
1	49	0.000	0	0	0			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
1	50	0.000	0	0	0			
1	51	0.000	0	0	0			
1	52	0.000	0	0	0			
1	53	0.000	0	0	0			
1	54	0.005	1	200	214			
1	55	0.005	1	200	214			
1	56	0.005	1	200	214			
1	57	0.000	0	0	0			
1	58	0.020	1	800	627			
1	59	0.000	0	0	0			
1	60	0.000	0	0	0			
1	61	0.000	0	0	0			
1	62	0.005	1	200	214			
1	63	0.000	0	0	0			
1	64	0.005	1	200	214			
1	65	0.005	1	200	214			
1	66	0.005	1	200	214			
1	67	0.000	0	0	0			
1	68	0.000	0	0	0			
1	69	0.000	0	0	0			
1	70	0.000	0	0	0			
1	71	0.005	1	200	214			
1	72	0.005	1	200	214			
1	73	0.000	0	0	0			
1	74	0.010	1	400	366			
1	75	0.010	1	400	366			
1	76	0.010	1	400	366			
1	77	0.000	0	0	0			
1	78	0.005	1	200	214			
1	79	0.020	1	800	627			
1	80	0.800	1	32,000	10,963			
1	81	0.000	0	0	0			
1	82	0.030	1	1,200	859			
1	83	0.010	1	400	366			
1	84	0.020	1	800	627			
1	85	0.000	0	0	0			
1	86	0.005	1	200	214	372	2,720	1,011,622
2	1	0.000	0	0	0			
2	2	0.000	0	0	0			
2	3	0.000	0	0	0			
2	4	0.000	0	0	0			
2	5	0.000	0	0	0			
2	6	0.000	0	0	0			
2	7	0.000	0	0	0			
2	8	0.000	0	0	0			
2	9	0.000	0	0	0			
2	10	0.000	0	0	0			

-Continued-

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
2	11	0.000	0	0	0			
2	12	0.000	0	0	0			
2	13	0.000	0	0	0			
2	14	0.000	0	0	0			
2	15	0.000	0	0	0			
2	16	0.000	0	0	0			
2	17	0.000	0	0	0			
2	18	0.000	0	0	0			
2	19	0.000	0	0	0			
2	20	0.000	0	0	0			
2	21	0.000	0	0	0			
2	22	1.000	1	40,000	13,035			
2	23	1.000	1	40,000	13,035			
2	24	0.000	1	4	10			
2	25	0.001	1	40	61			
2	26	0.005	1	200	214			
2	27	0.250	1	10,000	4,447			
2	28	0.001	1	40	61			
2	29	0.330	1	13,200	5,516			
2	30	0.010	1	400	366			
2	31	1.000	1	40,000	13,035			
2	32	0.020	1	800	627			
2	33	0.010	1	400	366			
2	34	1.000	1	40,000	13,035			
2	35	0.020	1	800	627			
2	36	0.010	1	400	366			
2	37	0.010	1	400	366			
2	38	0.001	1	40	61			
2	39	0.000	0	0	0			
2	40	0.250	1	10,000	4,447			
2	41	0.010	1	400	366			
2	42	0.010	1	400	366			
2	43	0.020	1	800	627			
2	44	0.020	1	800	627			
2	45	0.030	1	1,200	859			
2	46	0.000	0	0	0			
2	47	0.000	0	0	0			
2	48	0.000	0	0	0			
2	49	0.020	1	800	627			
2	50	0.020	1	800	627			
2	51	0.000	0	0	0			
2	52	0.330	1	13,200	5,516			
2	53	0.750	1	30,000	10,428			
2	54	0.250	1	10,000	4,447			
2	55	0.300	1	12,000	5,123			
2	56	0.000	1	4	10			
2	57	0.000	0	0	0			
2	58	0.000	0	0	0			

-Continued-

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| Transect No. | Quadrat | % Egg Cover | # Layers | Number of Eggs in Quadrat | | Mean Quadrat Egg Count within Transect ($\bar{y}$) | Total Possible Quadrats within M | Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$) |
				Field Estimate (x)	Adjust for Observer Bias (y)			
2	59	0.000	1	4	10			
2	60	0.400	1	16,000	6,404			
2	61	0.300	1	12,000	5,123			
2	62	0.250	1	10,000	4,447			
2	63	0.060	1	2,400	1,470			
2	64	0.250	1	10,000	4,447			
2	65	0.005	1	200	214			
2	66	0.250	1	10,000	4,447			
2	67	0.000	0	0	0			
2	68	0.000	0	0	0			
2	69	0.000	0	0	0			
2	70	0.000	0	0	0	1,798	2,214	3,980,040
3	1	0.000	0	0	0			
3	2	0.000	0	0	0			
3	3	0.005	1	200	214			
3	4	0.005	1	200	214			
3	5	0.000	0	0	0			
3	6	0.005	1	200	214			
3	7	0.005	1	200	214			
3	8	0.000	0	0	0			
3	9	0.000	0	0	0			
3	10	0.005	1	200	214			
3	11	0.010	1	400	366			
3	12	0.005	1	200	214			
3	13	0.010	1	400	366			
3	14	0.000	0	0	0			
3	15	0.005	1	200	214			
3	16	0.005	1	200	214			
3	17	0.005	1	200	214			
3	18	0.000	0	0	0			
3	19	0.000	0	0	0			
3	20	0.000	0	0	0			
3	21	0.000	0	0	0			
3	22	0.000	0	0	0			
3	23	0.000	0	0	0			
3	24	0.000	0	0	0			
3	25	0.000	0	0	0			
3	26	0.000	0	0	0			
3	27	0.000	0	0	0			
3	28	0.005	1	200	214			
3	29	0.005	1	200	214			
3	30	0.010	1	400	366			
3	31	0.000	0	0	0			
3	32	0.005	1	200	214			
3	33	0.000	0	0	0			
3	34	0.005	1	200	214			
3	35	0.020	1	800	627			
3	36	0.000	0	0	0			

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Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect $(\bar{y})$	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect $(M\bar{y})$
				Field Estimate (x)	Adjust for Observer Bias (y)			
3	37	0.000	0	0	0			
3	38	0.000	0	0	0			
3	39	0.000	0	0	0			
3	40	0.005	1	200	214			
3	41	0.005	1	200	214			
3	42	0.020	1	800	627			
3	43	0.005	1	200	214			
3	44	0.005	1	200	214			
3	45	0.000	0	0	0			
3	46	0.005	1	200	214			
3	47	0.000	0	0	0			
3	48	0.000	0	0	0			
3	49	0.000	0	0	0			
3	50	0.005	1	200	214			
3	51	0.000	0	0	0			
3	52	0.000	0	0	0			
3	53	0.000	0	0	0			
3	54	0.000	0	0	0			
3	55	0.000	0	0	0			
3	56	0.005	1	200	214			
3	57	0.000	0	0	0			
3	58	0.000	0	0	0			
3	59	0.000	0	0	0			
3	60	0.000	0	0	0			
3	61	0.000	0	0	0			
3	62	0.000	0	0	0			
3	63	0.000	0	0	0			
3	64	0.000	0	0	0			
3	65	0.000	0	0	0			
3	66	0.000	0	0	0			
3	67	0.000	0	0	0			
3	68	0.000	0	0	0			
3	69	0.000	0	0	0			
3	70	0.000	0	0	0			
3	71	0.000	0	0	0	93	2,245	209,674
4	1	0.000	0	0	0			
4	2	0.000	0	0	0			
4	3	0.000	0	0	0			
4	4	0.000	0	0	0			
4	5	0.000	0	0	0			
4	6	0.000	0	0	0			
4	7	0.000	0	0	0			
4	8	0.000	0	0	0			
4	9	0.000	0	0	0			
4	10	0.000	0	0	0			
4	11	0.000	0	0	0			
4	12	0.000	0	0	0			
4	13	0.000	0	0	0			

-Continued-

Transect No.	Quadrat	% Egg Cover	# Layers	Number of Eggs in Quadrat		Mean Quadrat Egg Count within Transect ($\bar{y}$)	Total Possible Quadrats within M	Estimated Number of Eggs Eggs Within Transect ($M\bar{y}$)
				Field Estimate (x)	Adjust for Observer Bias (y)			
4	14	0.000	0	0	0			
4	15	0.000	0	0	0			
4	16	0.000	0	0	0			
4	17	0.000	0	0	0			
4	18	0.000	0	0	0			
4	19	0.000	0	0	0			
4	20	0.000	0	0	0			
4	21	0.000	0	0	0			
4	22	0.000	0	0	0			
4	23	0.000	0	0	0			
4	24	0.000	0	0	0			
4	25	0.000	0	0	0			
4	26	0.001	1	40	61			
4	27	0.000	0	0	0			
4	28	0.000	0	0	0			
4	29	0.000	0	0	0			
4	30	0.000	0	0	0			
4	31	0.000	0	0	0			
4	32	0.000	0	0	0			
4	33	0.000	0	0	0			
4	34	0.000	0	0	0			
4	35	0.000	0	0	0			
4	36	0.001	1	40	61			
4	37	0.000	1	4	10			
4	38	0.000	0	0	0			
4	39	0.000	0	0	0			
4	40	0.000	0	0	0			
4	41	0.000	1	4	10			
4	42	0.000	0	0	0			
4	43	0.000	0	0	0			
4	44	0.000	0	0	0			
4	45	0.000	0	0	0			
4	46	0.000	0	0	0			
4	47	0.000	0	0	0			
4	48	0.000	0	0	0			
4	49	0.000	0	0	0			
4	50	0.000	0	0	0			
4	51	0.000	0	0	0			
4	52	0.000	0	0	0			
4	53	0.000	0	0	0			
4	54	0.000	0	0	0			
4	55	0.000	0	0	0			
4	56	0.000	0	0	0			
4	57	0.000	0	0	0			
4	58	0.000	0	0	0	2	1,834	4,533
Mean					578			1,301,467

Note: 10 m quadrat interval